Throughput and Time Sync Simulation in WSN with OPNET Tool

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Bachelor's Thesis

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SAVONIA UNIVERSITY OF APPLIED SCIENCES **THESIS Abstract**

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Abstract

The aim of this thesis was to simulate the time synchronization between a few client computers in the wireless sensor network environment. Besides, it was tested that how many clients could be served for the maximum. The protocol that was used was the NTP or IEEE 802.11.

WSN is widely used in modern society, OPNET is an important network simulation tool, which can be used for designing and analyzing of time synchronization protocol. In this project, combine them two together to make a virtual environment and make it working is the key point.

The results of this thesis, the maximum number of clients who could be served is three. And the normal speed is 2.4 Mbit/s. The accuracy between those client computers could be 2 ms.

Keywords
WSN, Time Synchronization, IEEE 802.11, NTP, OPENT

Acknowledgements

First of all, my deepest gratitude to my supervisor, Mr. Arto Toppinen, for giving me a chance to do this project. During the project, he gave me lots of help and taught me more about this topic. Thanks also to all teachers who taught me a lot of knowledge and skills to carry out this project.

And I also want to thank my parents who have supported me for these years and my friends who are from China.

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Kuopio, Finland

Jiawen Chen

Abbreviations

OPNET	Optimized Network Engineering Tool
NTP	Network Time Protocol
SNTP	Simple Network Time Protocol
IP	Internet Protocol
WLAN	Wireless local Area Network
IEEE	The Institute of Electrical and Electronics Engineering
WSN	Wireless Sensor network
MIMO	Multiple-input and multiple output
DSSS	Direct-sequence spread spectrum
FHSS	Frequency-hopping spread spectrum
OFDM	orthogonal frequency division multiplexing

1. Introduction

Time usually advances. If there are communicating programs running on different computers, time should even advances. Switching from one computer to another one. Obviously if one system is ahead of the others, the others are behind of the particular one. From the perspective of an external observer, switching between these systems would cause time to jump forwards and back, which is a non-desirable effect.

As a consequence, isolated networks may run their own wrong time, but as soon as possible you connect to the Internet, the effect will be visible. Imagine some email messages arriving five minutes before it was sent, and there were a reply two minutes before the message was sent.

Even on a single computer, some applications have trouble when time jump backwards. Database, systems using transactions and crash recovery like to know the time of the last good state.

OPNET is an important network simulation tool, which can be used for the designing and analyzing of a time synchronization protocol. A Local clock is necessary to time synchronization protocols such as NTP, IEE1588 while OPNET only provides a precise clock that records simulation time.

In this project, I’m working to accomplish time sync in two different devices with the OPNET tool.

In this paper there are some experimental results on the performance using OPNET.

2. About the Wireless Sensor Network

A wireless sensor network (WSN) combines embedded computing technology, microelectronic, networking and wireless communications technology and other advanced technologies. Because of the fast development, the WSN is getting more popular in the scientific and technological field.

2.1 Definition

The WSN is built of nodes—from a few to several hundreds or even thousand, where each node is connected to sensors. The WSN is a self-organizing wireless network system which is composed of a large number of tiny sensor nodes in the monitoring area. Its purpose is to collaborate in perception, acquisition and processing of the network coverage area to perceive the object of information, and send it to the observer. These sensor nodes combine with a router and a gateway to produce a wireless network system. [1]

Sensor networks are the key to gathering the information needed by smart environments, whether in buildings, utilities, industrial process monitoring and control, home automation, traffic control, or elsewhere. A sensor network which is quick and easy to install and maintain is required. Here are some examples of WSN in life, see Fig. 2.1

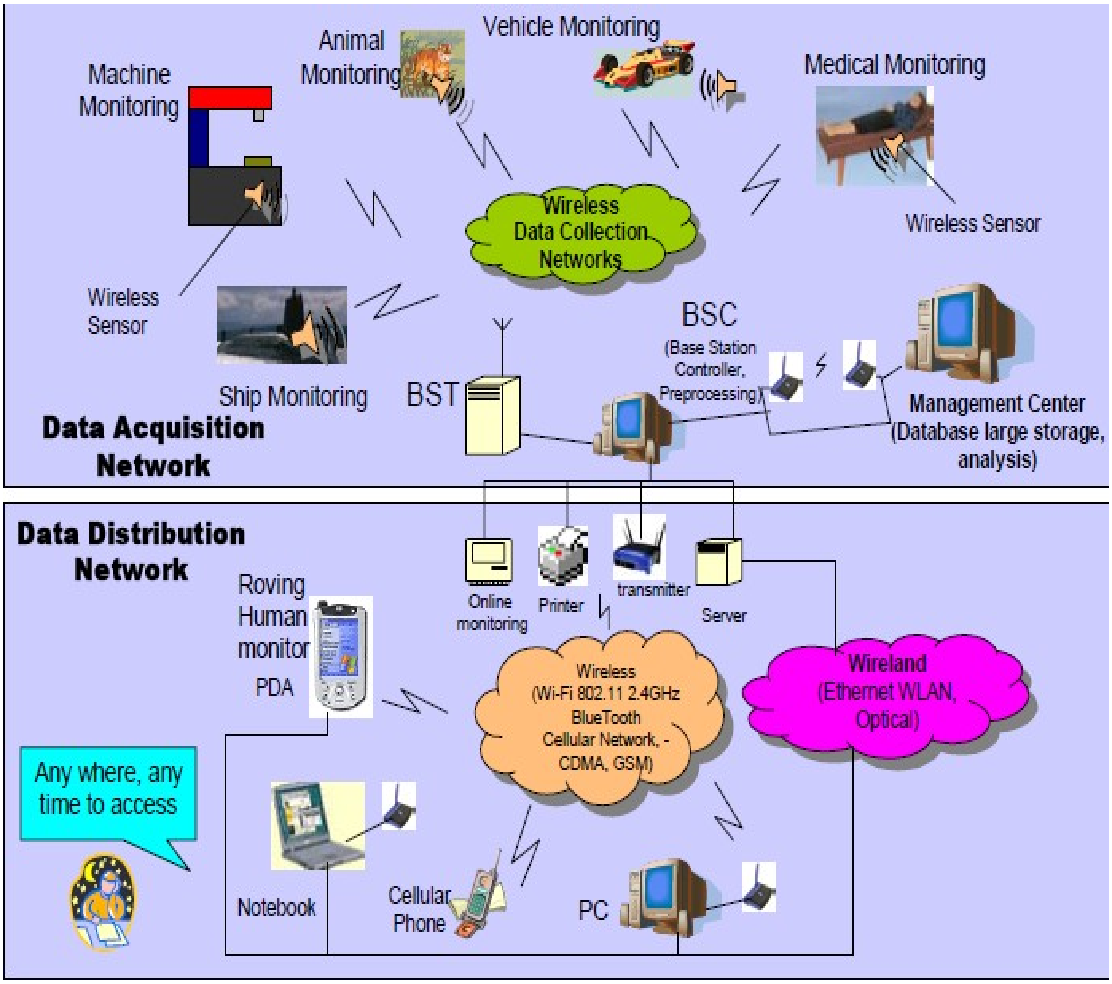


Fig 2.1 wireless sensor networks

2.2 Definition of node

In a network, a node is a connection point, either a redistribution point or an end point for data transmissions. In general, a node has programmed or engineered capability to recognize and process or forward transmissions to other nodes. Fig. 2.2 shows a picture of a router.

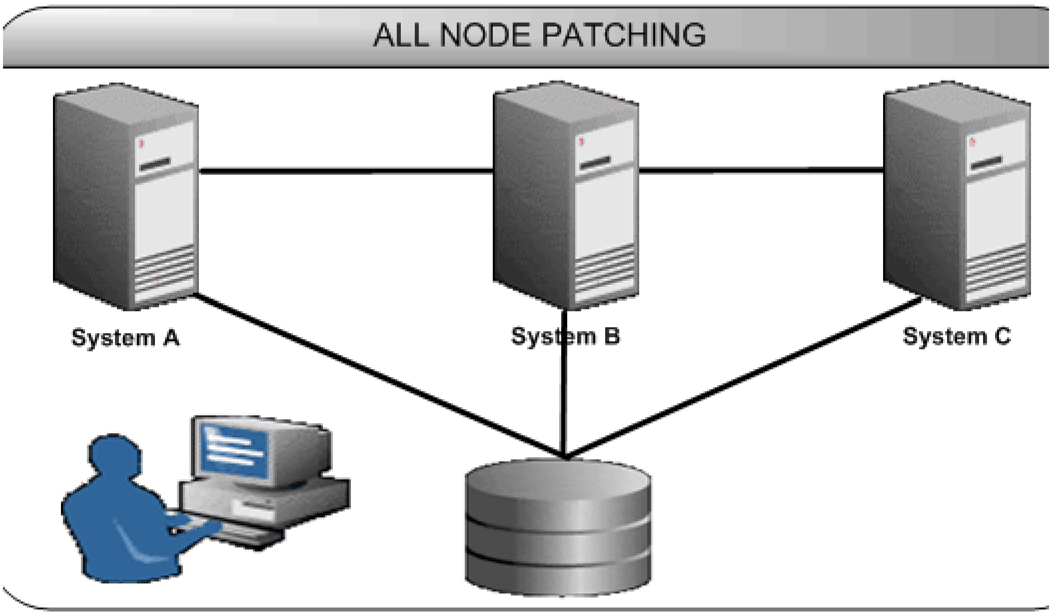


Fig 2.2 node patching

2.3 Pros and Cons of WSN

Due to the advantages and disadvantages comparing, it is more effective to use WSN. [1]

Advantages:

(1) It avoids a lot of wiring

(2) It can accommodate new devices at any time

(3) It is flexible to go through physical partitions

(4) It can be accessed through a centralized monitor

Disadvantages:

(1) It’s easy for hackers to hack because of controlling propagation of waves.

(2) Comparatively low speed of communication

(3) Gets distracted by various elements like Blue-tooth

(4) Still costly at large

Except for all above, there are some characteristics of WSN.

Defining characteristics of WSNs

(1) Wireless nodes

(2) Energy efficiency critical

(3) Difficult or impossible to replace battery

(4) Large scale and sensor fields may have thousand or million of nodes.

(5) Frequently nodes have low duty cycle, periodic temperature reports

(6) Scalable node capacity, only limited by bandwidth of gateway node.

3. NTP

Time synchronization is one of the basic components in a WSN, time synchronization is not only the WSN applications necessary for normal operation, its reliability is unmatched in the industry. The machine clock can be set to an accuracy of < 10 milliseconds. Time sync can maintain the correct time even if the time source is unavailable sporadically. Normally the best choice for time sync is NTP or IEEE 1588, so in this chapter, section 3.1 describe the basic knowledge and concepts of protocol, section3.2 describe the traditional time sync protocol of NTP, section 3.3 introduces the highest precision sync protocol IEEE 1588.[7]

3.1 Definition of protocol

In information technology, a protocol is the special set of rules that end points in a telecommunication connection use when they communicate. Protocols exist at several levels in a telecommunication connection. For example, there are protocols for the data interchange at the hardware device level and protocols for data interchange at the application program level. In the standard mode known as open systems interconnection, there are one or more protocols at each layer in the telecommunication exchange that both ends of the exchange must recognize and observe. Protocols are often described in an industry or international standard.

3.2 NTP

NTP stands for network time protocol, and it is an internet protocol used to synchronize the clock computers to some time reference. It is the longest running, continuously operating, and distributed application in the Internet. As NTP is approaching its third decade, it is of historic interest to document the origins and evolution of the architecture, protocol and algorithms.

NTP is one of the oldest internet protocols still in use. NTP was originally designed by Dave Mills of the University of Delaware, who still maintains it, along with a team of volunteers. [2]

3.2.1 Features of NTP

There are some features of NTP [3]:

(1) NTP needs some reference clock that defines the true time to operate. All clocks are set towards that true time. It will not only make all systems agree on some time, but will make them agree upon the true time as defined by some standard. NTP uses UTC (universal coordinated time).

(2) NTP is a fault-tolerant protocol that will automatically select the best of several available time sources to synchronize some multiple

candidates who can be combined to minimize the accumulated error. Temporarily or permanently insane time sources will be detected and avoided.

(3) NTP is highly scalable: A synchronization network may consist of several reference clocks. Each node of such a network can exchange time information in bidirectional or unidirectional way. Propagating time from one node to another forms a hierarchical graph with reference clocks at the top.

(4) Having available several time sources, NTP can select the best candidates to build its estimate of the current time. The protocol is highly accurate, using a resolution of less than a nanosecond (2^-32 seconds).

(5) Even when a network connection is temporarily unavailable, NTP can use measurements from the past to estimate current time and error.

(6) For formal reasons NTP will also maintain estimates for the accuracy of the local time.

Fig 3.2 shows the working principle of NTP:

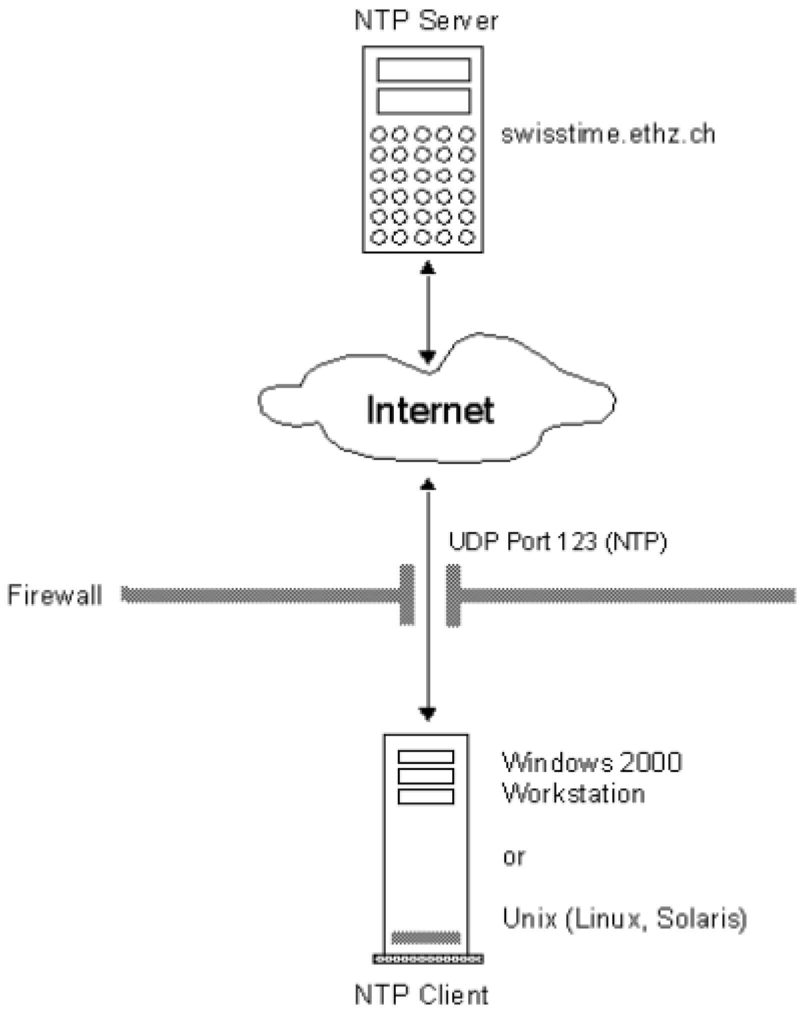


Fig 3.2 Example of NTP

3.2.2 The number of available NTP servers on the Internet

According to A Survey of the NTP Network there were at least 175,000 hosts running NTP on the Internet. Among these there were over 300 valid stratum-1 servers. In addition, there were over 20,000 servers at stratum 2, and over 80,000 servers at stratum 3.

3.2.3 NTP Development

The operational details for NTP are: RFC 778, RFC 891, RFC 956 and RFC 1305. With the development of the technology, the latest of NTP implementation is NTPv4.

Now take a look at the evolution to NTP Version 4:

- Current NTPv3 was been in use from 1992 , with nominal accuracy in the low milliseconds
- Nowadays workstations and networks are faster, with more attainable accuracy in low microseconds.
- In 1994, NTPv4 made suggestions for improvement. The improvements include clock adjustment algorithm and communication patterns.
- There is another branch of NTP. It is a simple network time protocol.
- NTPv4 supports new platforms and operating systems and it was a faster synchronization at startup and after network failures.

3.2.4 Clock Strata

Normal time protocol takes use of a hierarchical clock sources. Each level we could call it a strata/stratum. The stratum begins with 0 at the top. Strata level means its distance from the reference clock. It also prevents cyclical dependencies in the level. Here we could see a picture about the NTP clock stratum.

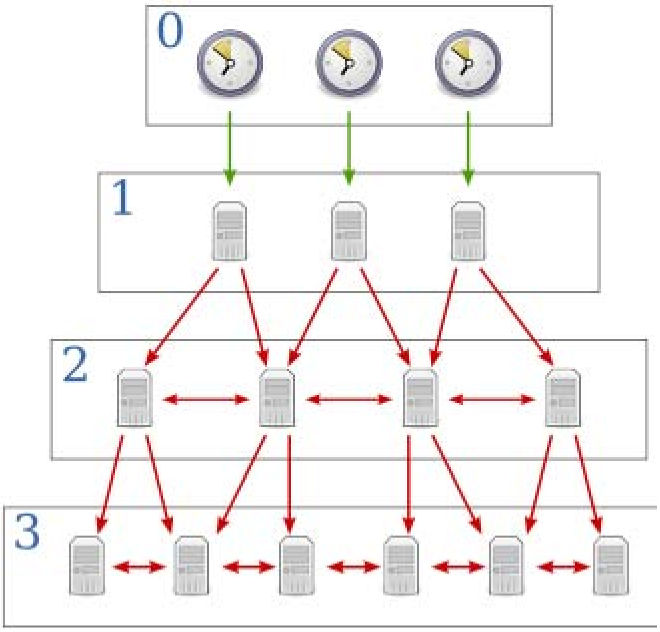


Fig 3.3 NTP clock strata

As we know above, here we can list the different level:

Stratum 0

These are devices such as atomic clocks, GPS clocks. Stratum-0 devices are traditionally not attached to the network; instead they are locally connected to computers.

Stratum 1

These are computers attached to Stratum 0 devices. Generally they act as servers for timing requests from Stratum 2servers via NTP. The computers are also referred to as time servers.

Stratum 2

These computers are sending NTP request to stratum 1 servers. Normally a stratum 2 computer will reference a number of Stratum 1 servers and use the NTP algorithm to gather the best data sample, dropping any Stratum 1 servers that seem obviously wrong. Stratum 2 computers will peer with other Stratum 2 computers to provide more stable and robust time for all devices in the peer group. Stratum 2 computers normally act as servers for Stratum 3 NTP requests.

Stratum 3

These computers employ exactly the same NTP functions of peering and data sampling as Stratum 2, and can themselves act as servers for lower strata. NTP (depending on what version of NTP protocol in use) supports up to 256 strata. [4]

4. IEEE802.11

IEEE 802.11 is a set of standards for implementing wireless local area network computer communication in different frequency bands like 2.4, 3.6 and 5 GHz. IEEE LAN/MAN Standard Committee maintain them. The basic current version is IEEE 802.11-2007.

4.1 Comprehensive Description

802.11 families are composed of a series of over-the-air modulation techniques which use the same basic protocol. The most popular are those defined by 802.11b and 802.11g protocols, they are improvements to the original first wireless networking standard, but 802.11b was the first widely accepted one, then there were 802.11g and 802.11n. 802.11 technology has its origins in a 1985 ruling by the U.S. Federal Communications Commission that released the ISM band for unlicensed use.

In 1991 NCR Corporation invented the precursor to 802.11. The inventors initially intended to use the cashier systems; the first wireless products were brought on the market under the name Wave LAN with raw data rates of 1 Mbit/s and 2Mbit/s. [8]

4.2 Details and data rate

Table 4.2 shows different types of 802.11 and their frequency and data rates.

Table 4.2 the details of IEEE 802.11

802.11 Network Standard						
802.11 protocol	Release	Freq (GHz)	Bandwidth (MHz)	Data rate per stream(Mbit/s)	Allowable MIMO streams	Modulation
—	Jun 1997	2.4	20	1, 2	1	DSSS,FHSS
a	Sep 1999	5 3.7	20	6, 9, 12, 18, 24, 36, 48, 54	1	OFDM
b	Sep 1999	2.4	20	5.5, 11	1	DSSS
g	Jun 2003	2.4	20	6, 9, 12, 18, 24, 36, 48, 54	1	OFDM DSSS
n	Oct 2009	2.4/5	20	7.2, 14.4, 21.7, 28.9, 43.3, 57.8, 65, 72.2	4	OFDM
			40	15, 30, 45, 60, 90, 120, 135, 150		

5. OPNET

OPNET is a high level event based network tool which could do simulation, it contains a lot of accurate models, fixed network hardware and protocols.

It can also be used as a research tool or a network design/analysis tool.

My project aim is to simulate the time sync and check how many clients we could serve at the same time.

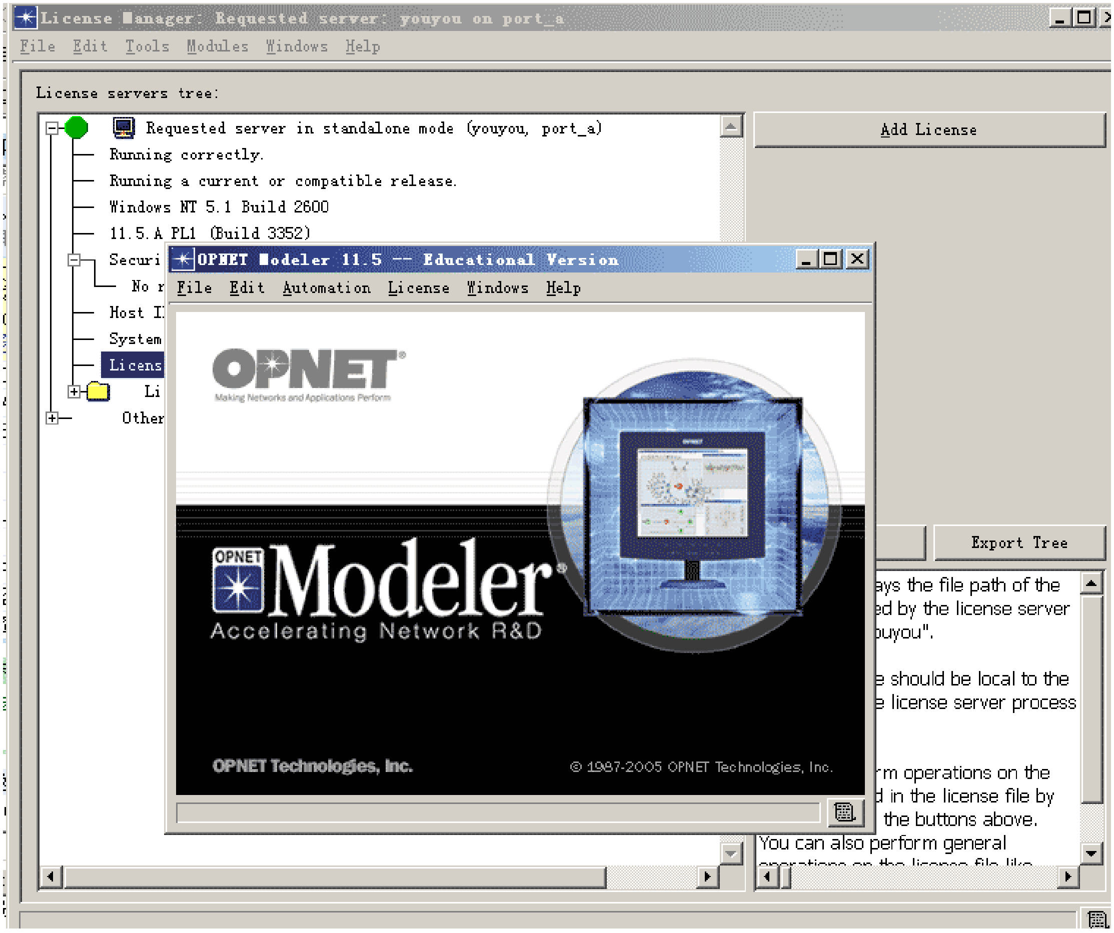


Fig. 5.1 the modeler of OPNET

The performance evaluation of the routing protocols needs different kinds of parameters. Three parameters will be used to test and compare overall network performance. These parameters are delay, network load, and throughput for protocols evaluation. In a communication network, that Delay, network load, and throughput are very important consideration when evaluate the routing protocols performance. These performances will be seen by the customers and checked by engenderers. Through the performance it first check the success of network, and it will also help and make the network more security and efficient.

5.1 Delay

Delay specifies how long it takes for a bit of data to travel across the network from one to another. It is typically measure in multiples or fractions of second. In most situations, there are mote than one node, so source destination and network configuration could be used to calculate the delay. Here below we could see the equation [11]:

$$d_{end\_end} = N[d_{trans} + d_{prop} + d_{proc}] \qquad (1)$$

d_{end_end} means the end to delay

d_{trans} means time it takes to push the packet's bit on link

d_{prop} means time for a signal to reach its destination

d_{proc} means time for routers take to process the packet header

5.2 Network Load

Network load stands for the total load in bit/sec unit in WLAN layers. When running a model, there is more traffic coming to the network (in this project, we set up the origin traffic to 2.34 Mbps) and hard to control, then called network load. It is like when downloading some movies or songs from internet, you could apparently see the internet speed is slower, it is due to the load is heavier. In successful networks which could handle large traffic easily. If the network load is heavy, that would directly affect the stable state.

5.3 Throughput

Throughput is the number of message/data successfully delivered per unit time. It is controlled by available bandwidth, as well as the signal to noise ratio, frequency and hardware limitations. Throughput is to be measure from the arrival of the first bit of data at the receiver. This data could be delivered over a physical or logical link, or passing through a certain network node. System throughput or aggregate throughput is the sum of the data rates that are delivered to all terminals in a network. [12]

It could be analyzed mathematically by means of queuing theory, where the load in packets per time unit is denoted arrival rate λ, and the throughput in packets per time unit is denoted departure rate μ.

Maximum throughput

Users of telecommunications devices, systems designers, and researchers into communication theory are often interested in knowing the expected performance of a system. From a user perspective, this is often phrased as either "which device will get my data there most effectively for my needs?", or "which device will deliver the most data per unit cost?" Systems designers are often interested in selecting the most effective architecture or design constraints for a system, which drive its final performance. In most cases, the benchmark of what a system is capable of or its 'maximum performance' is what the user or designer is interested in. When examining throughput, the term 'Maximum Throughput' is frequently used where end-user maximum throughput tests are discussed in detail. [16]

Maximum throughput is essentially synonymous to digital bandwidth capacity.

The factors affecting throughput are: analog limitations, IC hardware considerations, protocol considerations and multi-users considerations.

6. Simulation in OPNET

6.1 Creating a new project

There are steps which show how to create and finish the project.

1. Double click on the OPNET icon, in the menu choose File---New----Project, give the project a name such as Time Sync; set the scenario name as test 1, and then click ok. (See Fig 6.1)

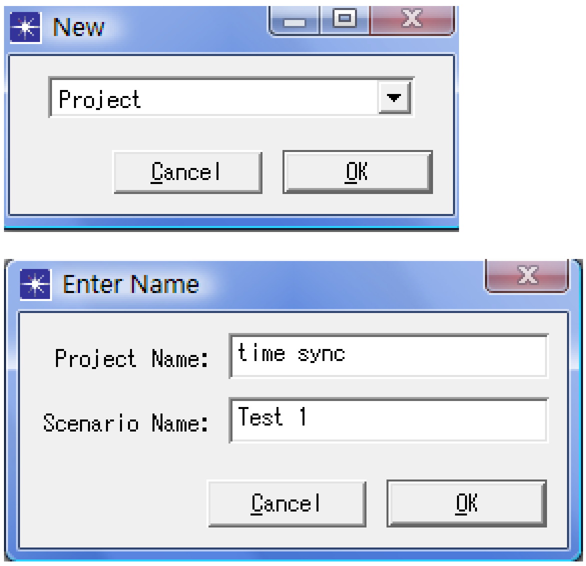


Fig 6.1 set up the project

2. Now create the empty scenario, and click next button.(see Fig 6.2)

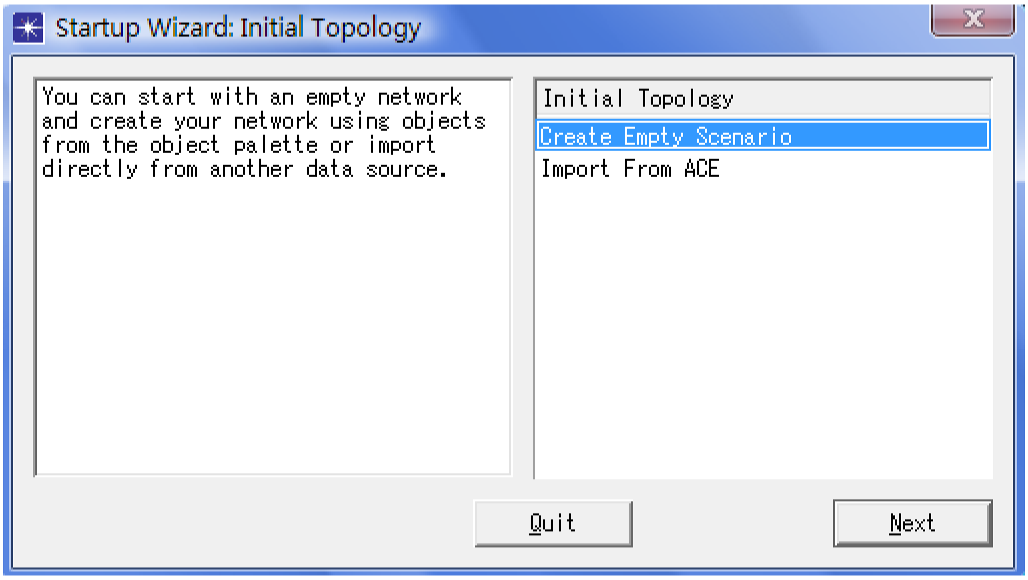


Fig 6.2 create scenario

3. Choose the enterprise in the network scale, and then click the next button. (see Fig 6.3)

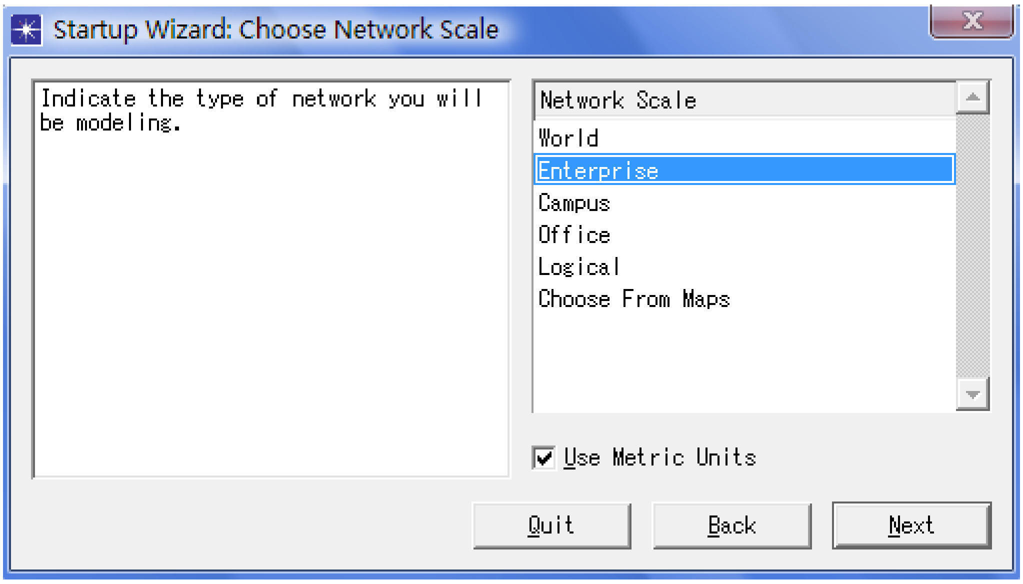


Fig 6.3 select the network scale

4. Choose specify size and set up the X and Y span which we could set them to 800 and 600 meters. (See Fig 6.4)

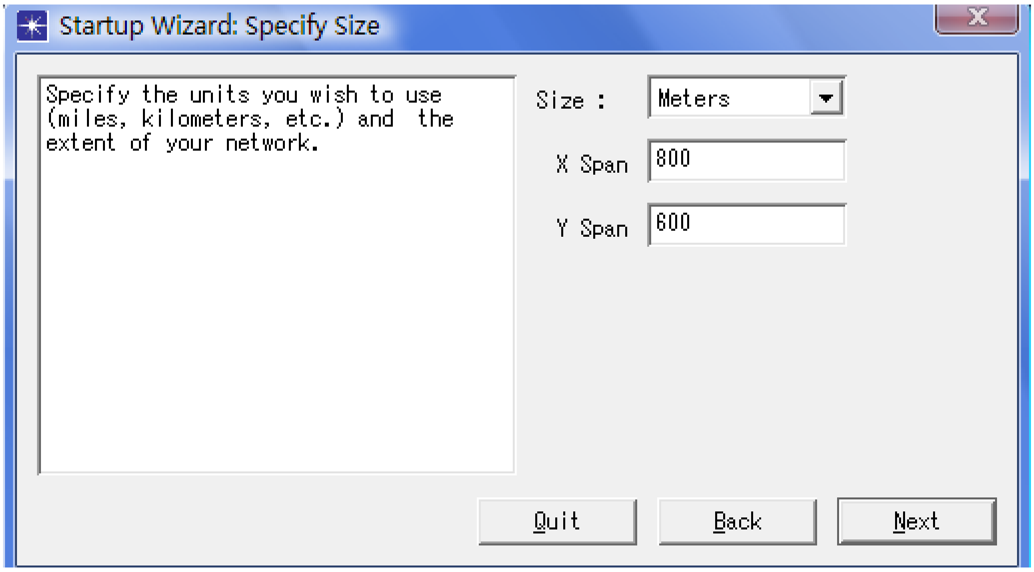


Fig 6.4 set up the size

5. Choose wireless_lan and Ethernet in technologies. (See Fig 6.5)

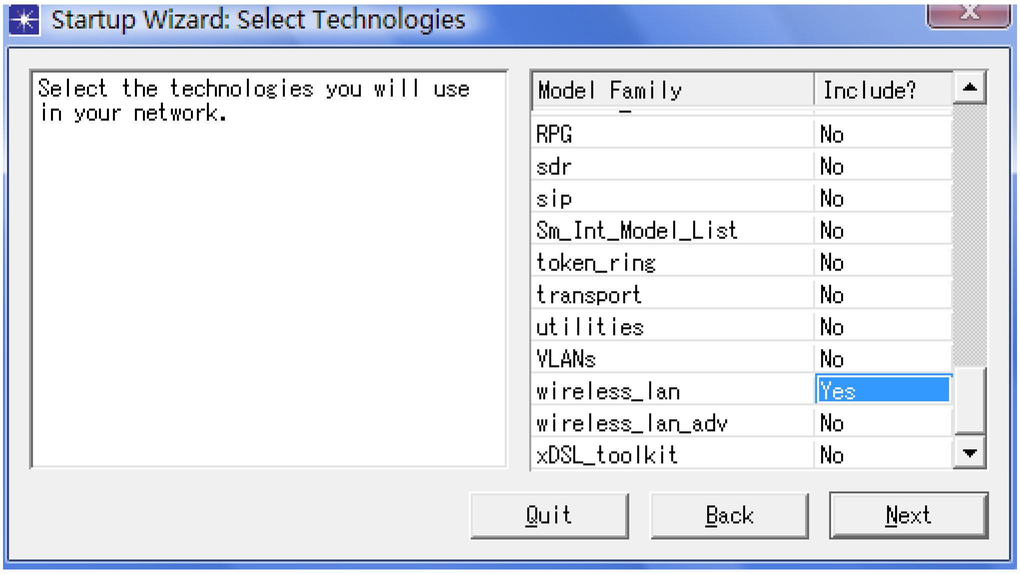


Fig 6.5 select technologies

6.2 Setting up the simulation with 4 clients

1. The object palette tree shows all the devices which we need in the experiment for WLAN, because we need one server, one AP(access point), four clients and two configuration objects-----profile configuration and application configuration. We could choose server from server AMD , and then choose 2200MHz WinXP(see Fig 6.6) and then choose the AP and clients(workstations) from wireless_lan.(see Fig 6.7)

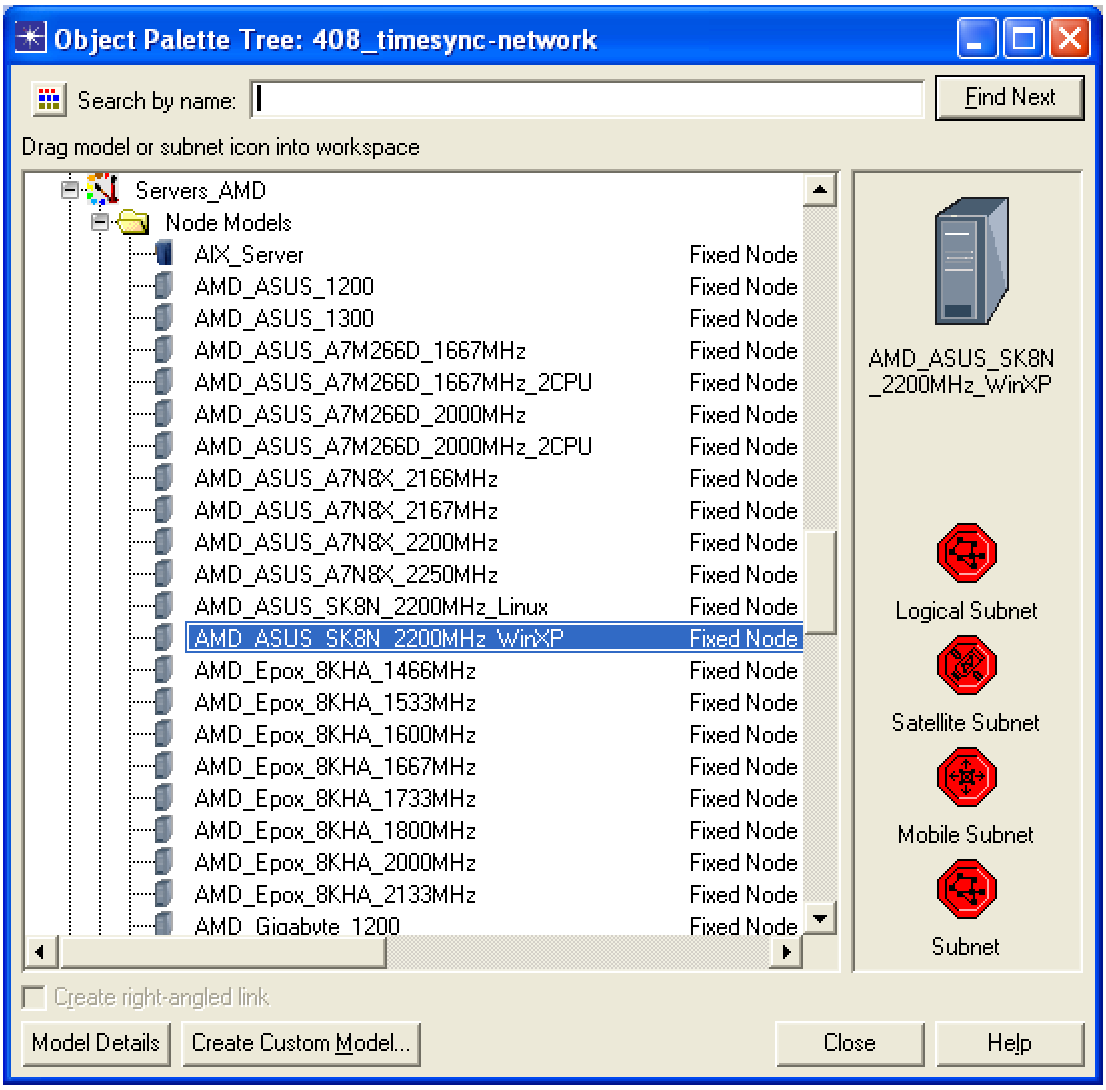


Fig 6.6 select server

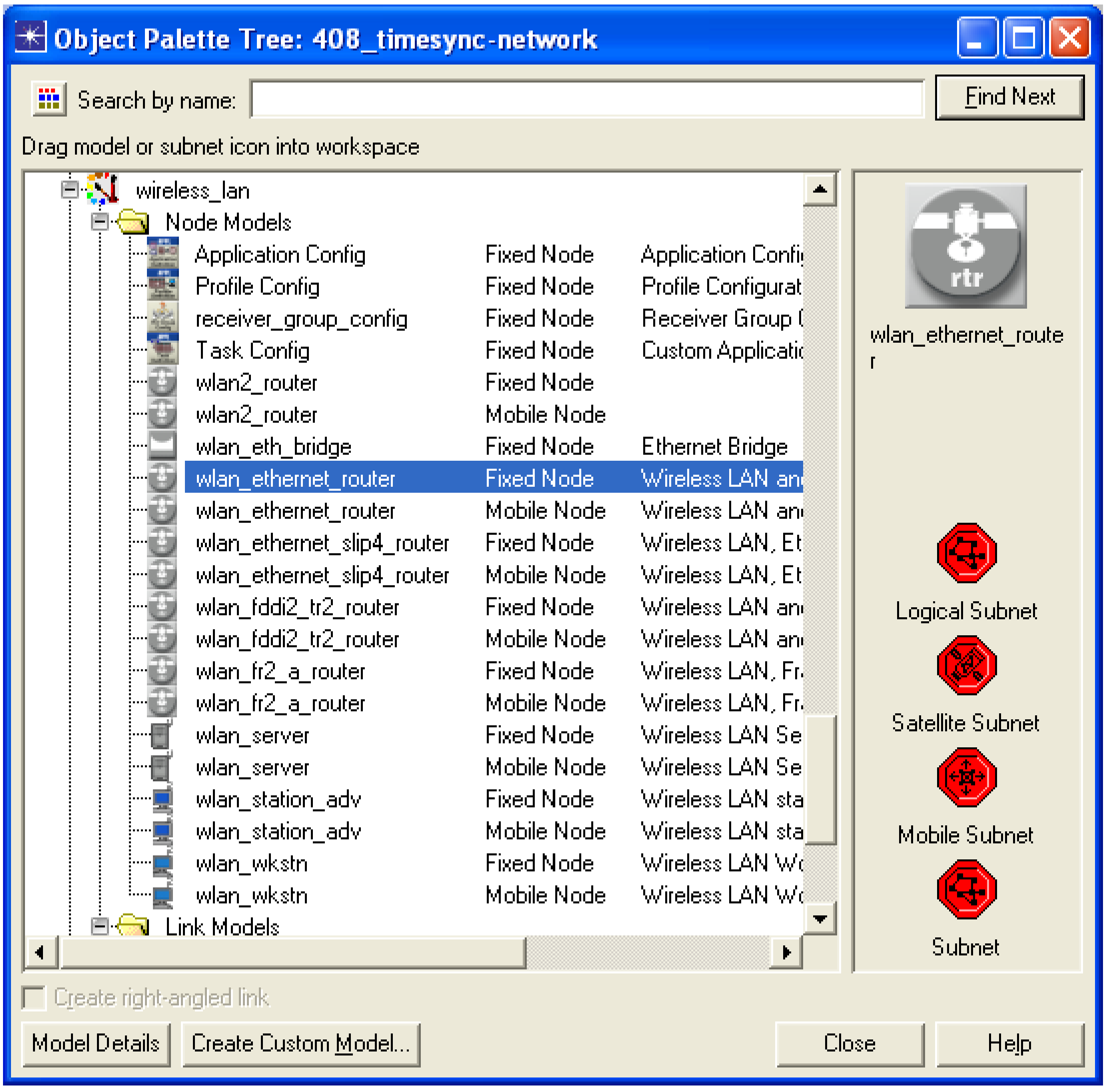


Fig. 6.7 Select AP and workstations

2. First putting these devices like in Fig 6.8.

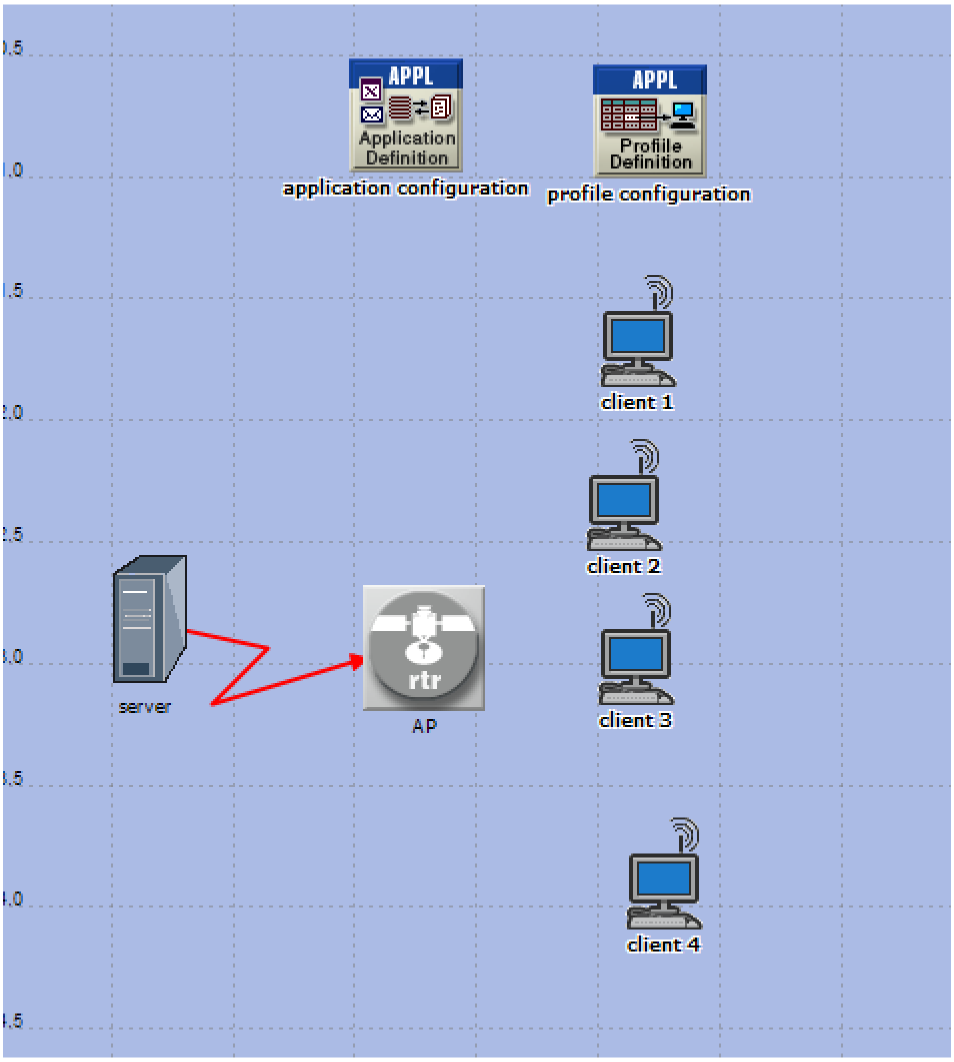


Fig 6.8 the layout of project

3. Right click on the server------choose edit attributes (advanced) ----choose IP Multicast Parameters-----choose Multicast routing and load splitting to enable. See Fig 6.9 and 6.10

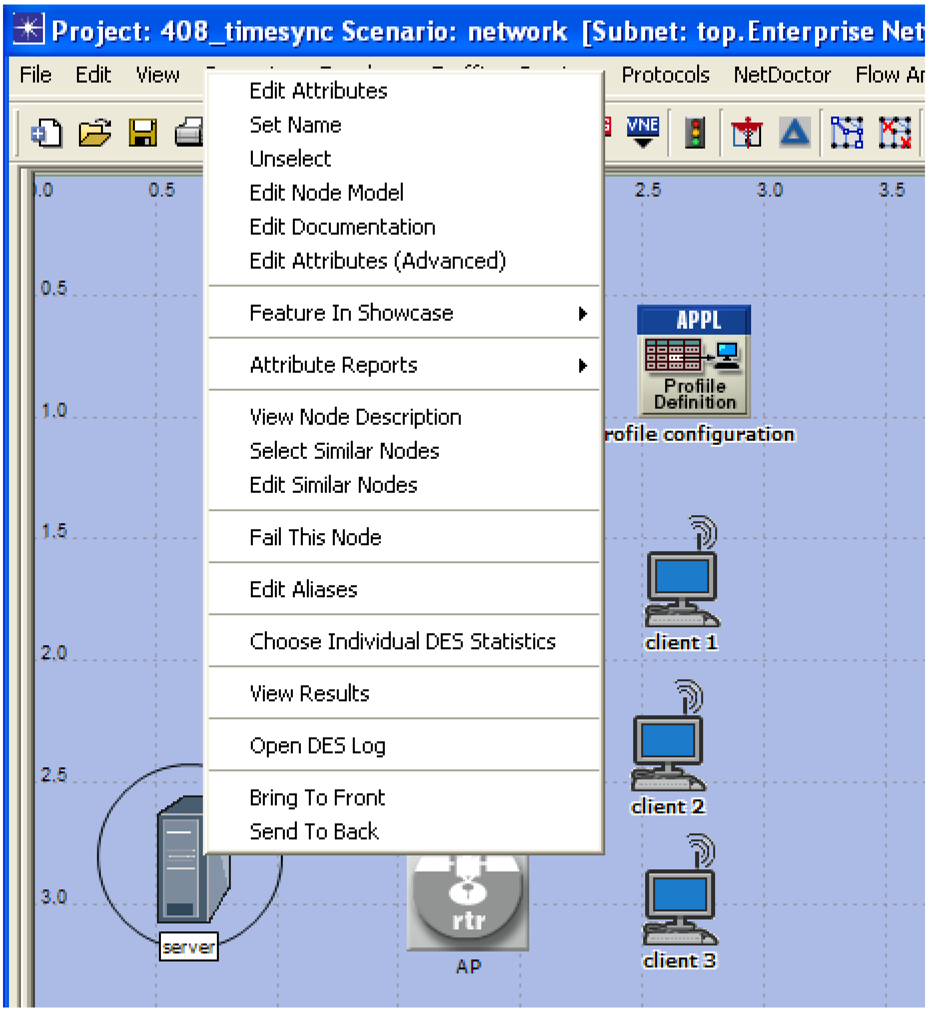


Fig 6.9 Edit attributes

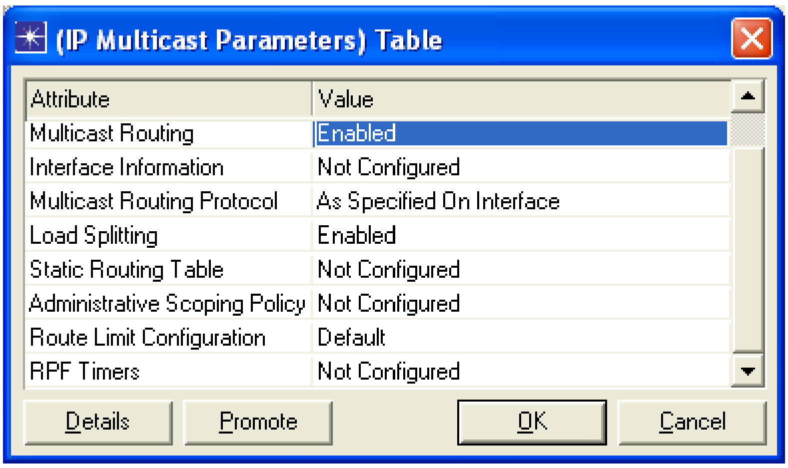


Fig 6.10 setting up the parameters for server

4. Right click on the AP----choose edit attributes----set forwarding rate units from packet/second to bits/second. See Fig. 6.11

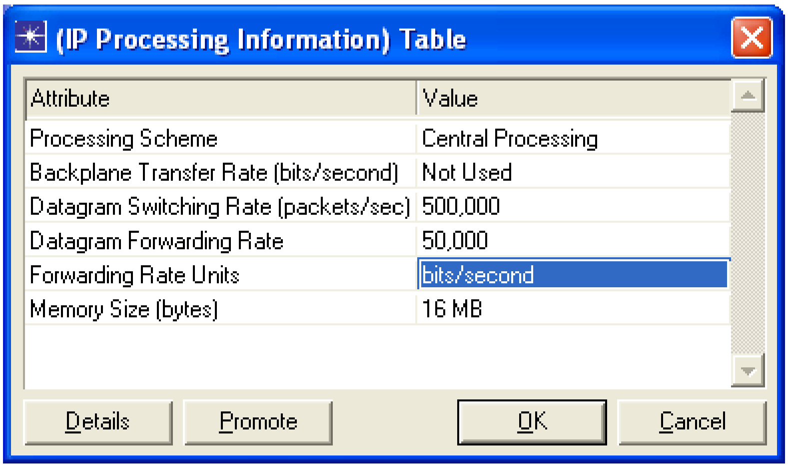


Fig 6.11 setting up the AP

5. Right click on any of the four workstations; select edit attributes----Wireless LAN----wireless LAN parameters. Click wireless LAN parameters, set large packet processing is fragment, fragment threshold value is 1024, and set the bandwidth to 10, Min Frequency to 30 in Channel Setting Edit. Here are pictures below show this procedure.(see Fig 6.12;6.13;6.14)

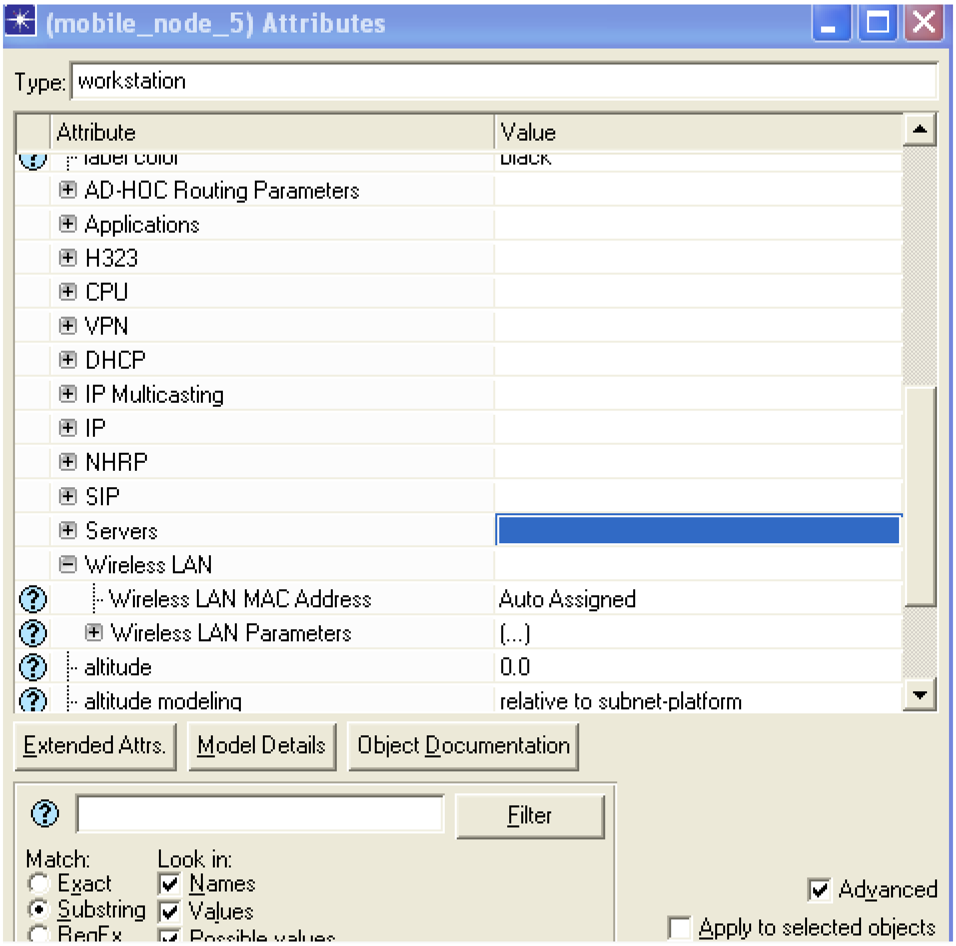


Fig 6.12 Wireless LAN Parameters

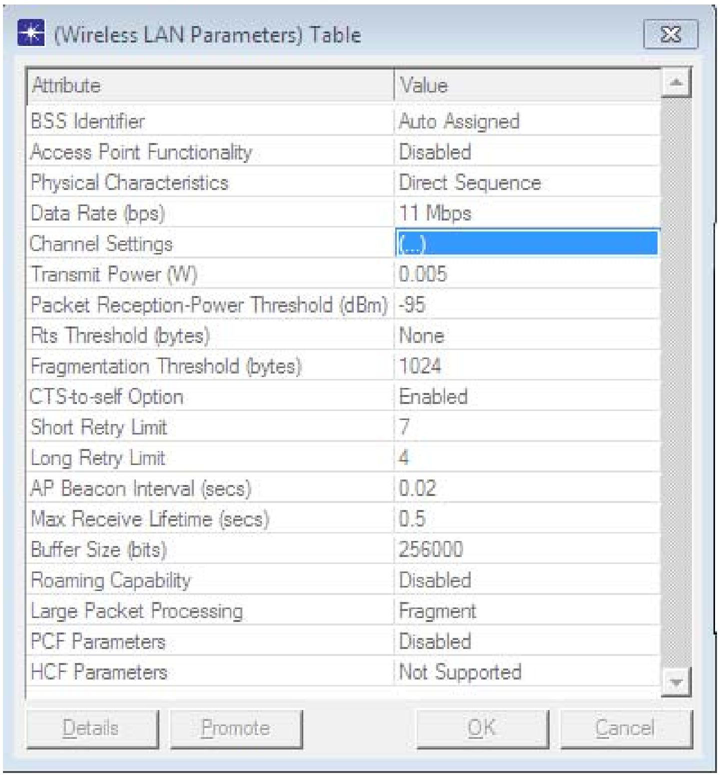


Fig 6.13 Wireless LAN Parameters table

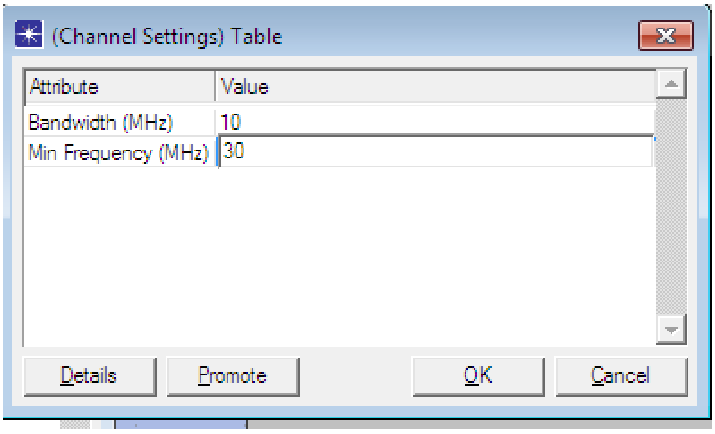


Figure 6.14 Channel Setting

6.3 Setting the route

1. Choose Control Panel----Topology----Define Trajectory, set the trajectory type as fixed interval, altitude as 5, and time step as 5 minutes. At the end, click define path. (See Fig. 6.15)

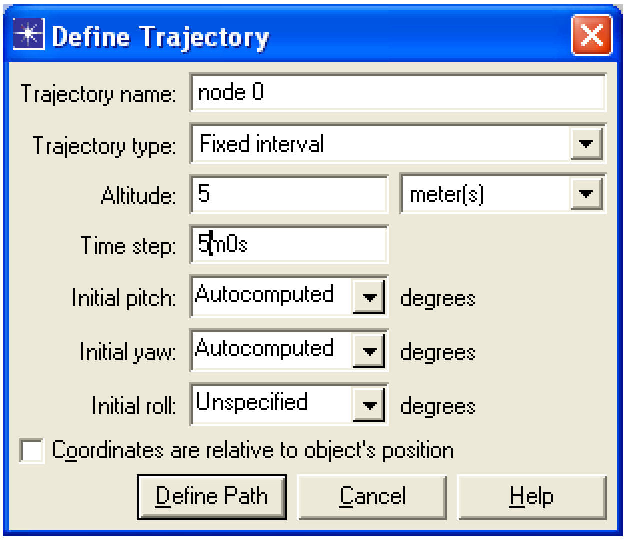


Fig 6.15 Trajectory parameters

2. Start from the server to the router, there is a red line shown, then right click the complete trajectory definition. (See Fig. 6.16)

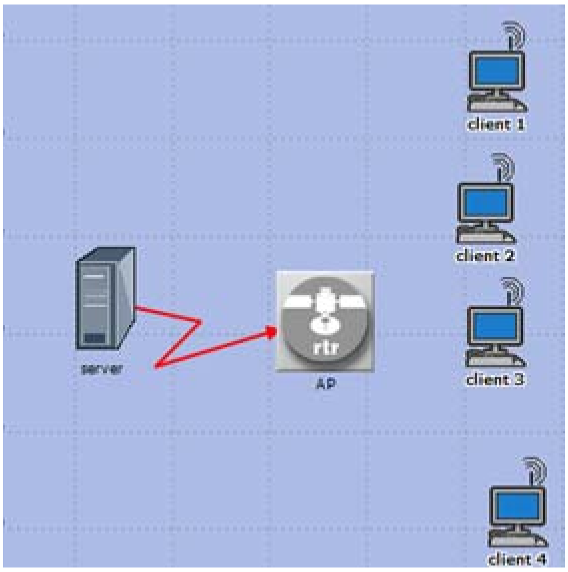


Fig 6.16 setting the trajectory

3. After set the trajectory from server to AP, do the same steps from AP to each client. (See Fig. 6.17)

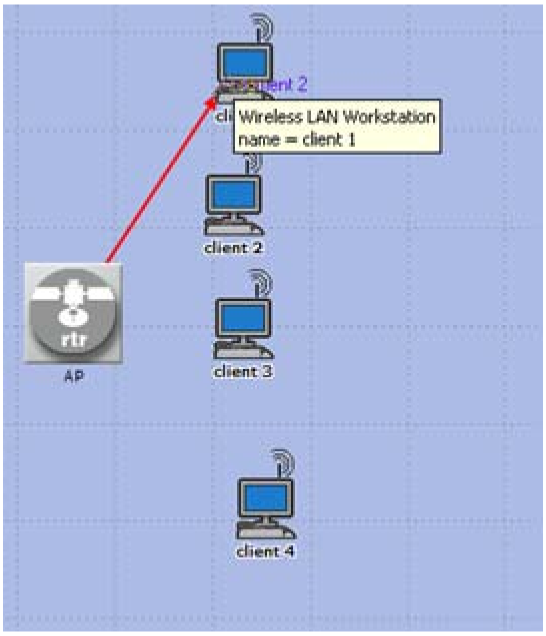


Fig 6.17 the route from AP to clients

6.4 Setting the configurations

To set up and configure any application in OPNET, the users must add the application configuration and profile configuration modules. The application configuration module contains the application definitions, while the profile configuration contains the profiles of user behaviors, like describe how the users employ the application definition in the application configuration module.

1. First change some parameters in Application Configuration; Select Advanced Edit Attributes.

2. Select Edit from the Application Definitions Attribute.

3. Set the number of rows to 4. Each row is: light web, heavy web, low ftp and high ftp. (See Fig. 6.18)

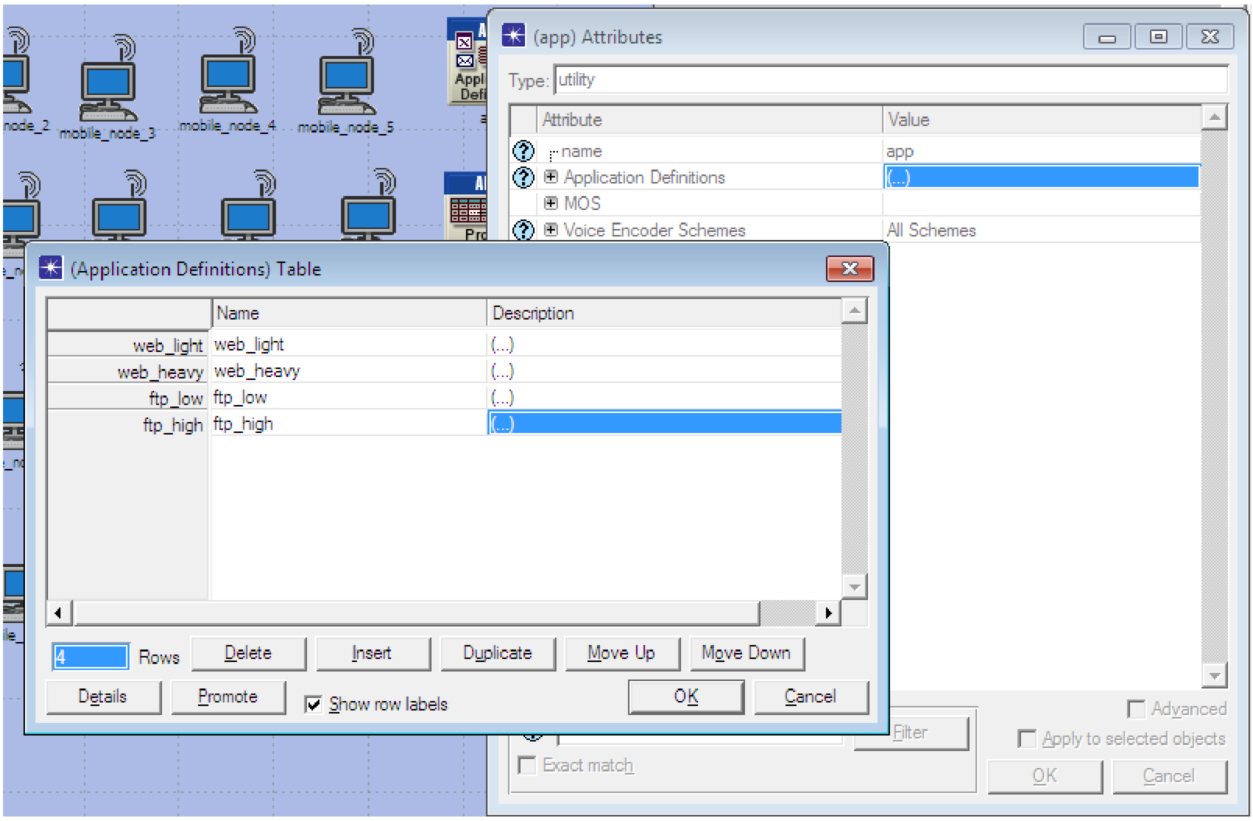
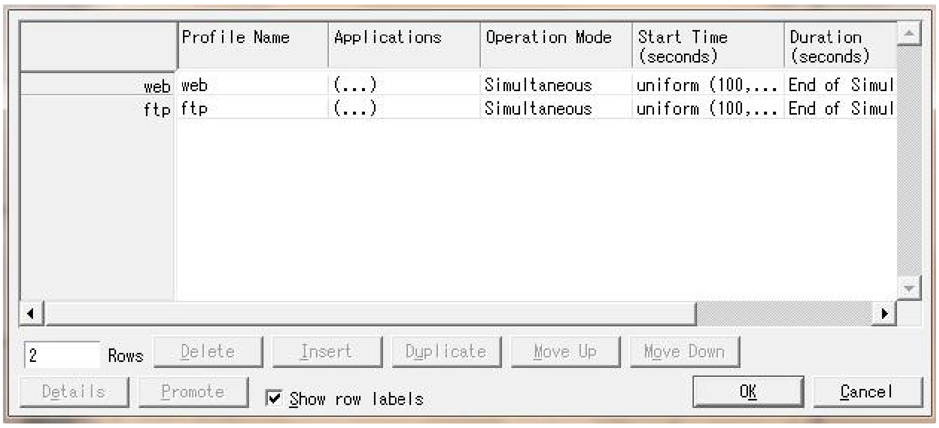


Fig 6.18 Application Config parameters

4. Do the same steps on the Profile Config, click Edit Attributes and chagne some parameters.
5. Make two rows, one is web and one is ftp,
6. Click ok (See Fig. 6.19)



	Profile Name	Applications	Operation Mode	Start Time (seconds)	Duration (seconds)
web	web	(...)	Simultaneous	uniform (100,...	End of Simul
ftp	ftp	(...)	Simultaneous	uniform (100,...	End of Simul

Fig 6.19 Table of Profile Config

6.5 Making other scenarios

The aim of this project is to test diffierent results with diffirent clients, so open new scenarios with 1 client, 2 clients, 3clients. See Fig 6.20;6.21;6.22.

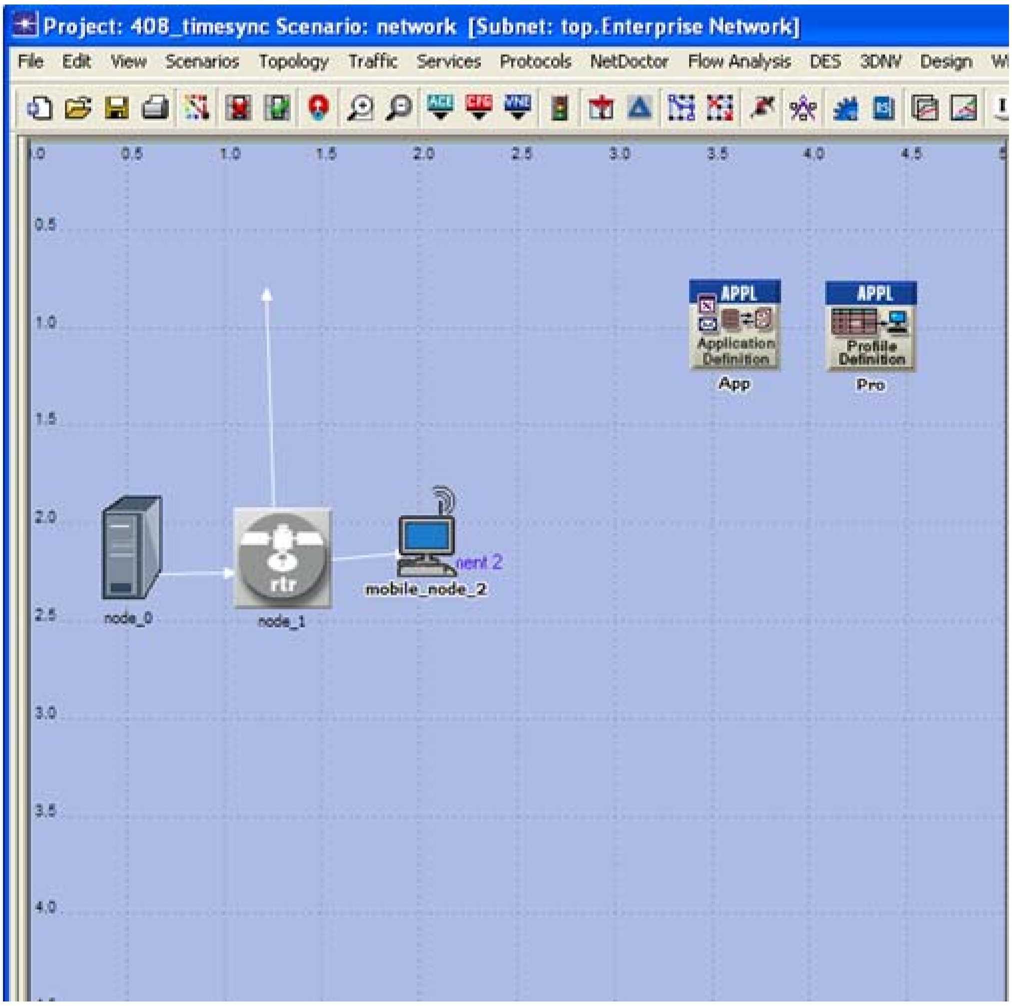


Fig 6.20 One client

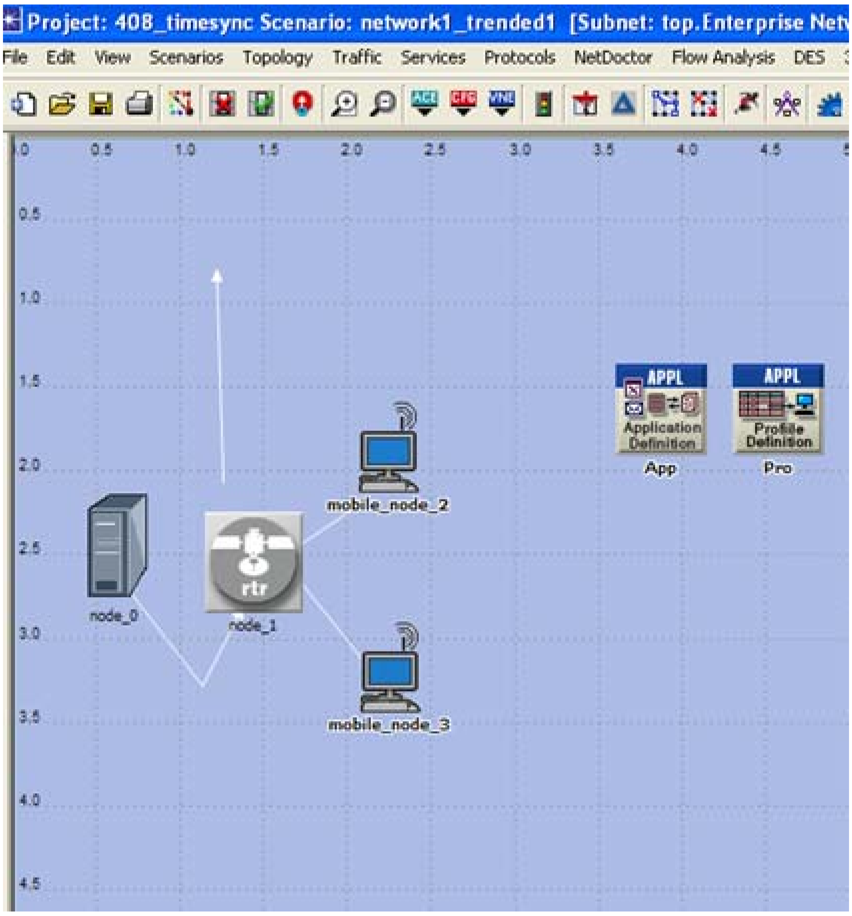


Fig 6.21 Two Clients.

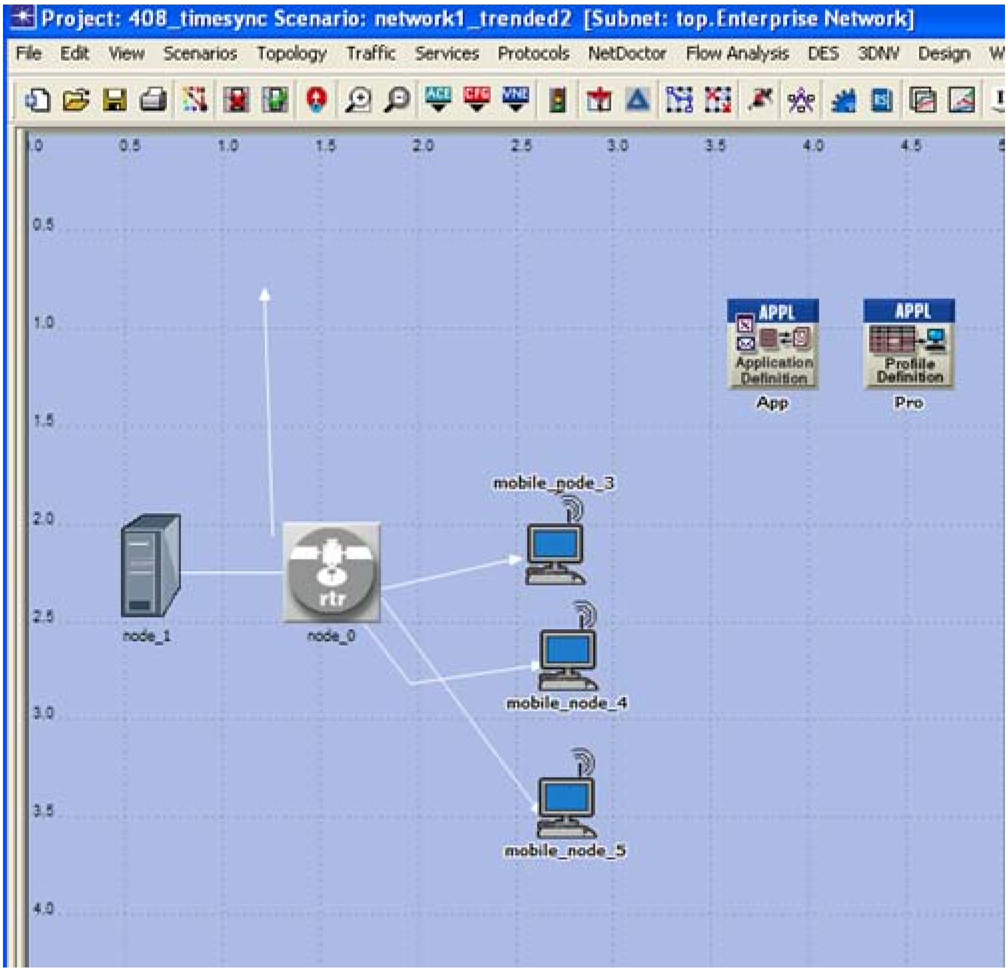


Fig 6.22 Three clients.

6.6 Testing

1. Right click on the space then choose Individual Statistics. See Fig. 6.23

2. Select Wireless LAn seperately in Global Statistics and Node Statistics, then click ok.

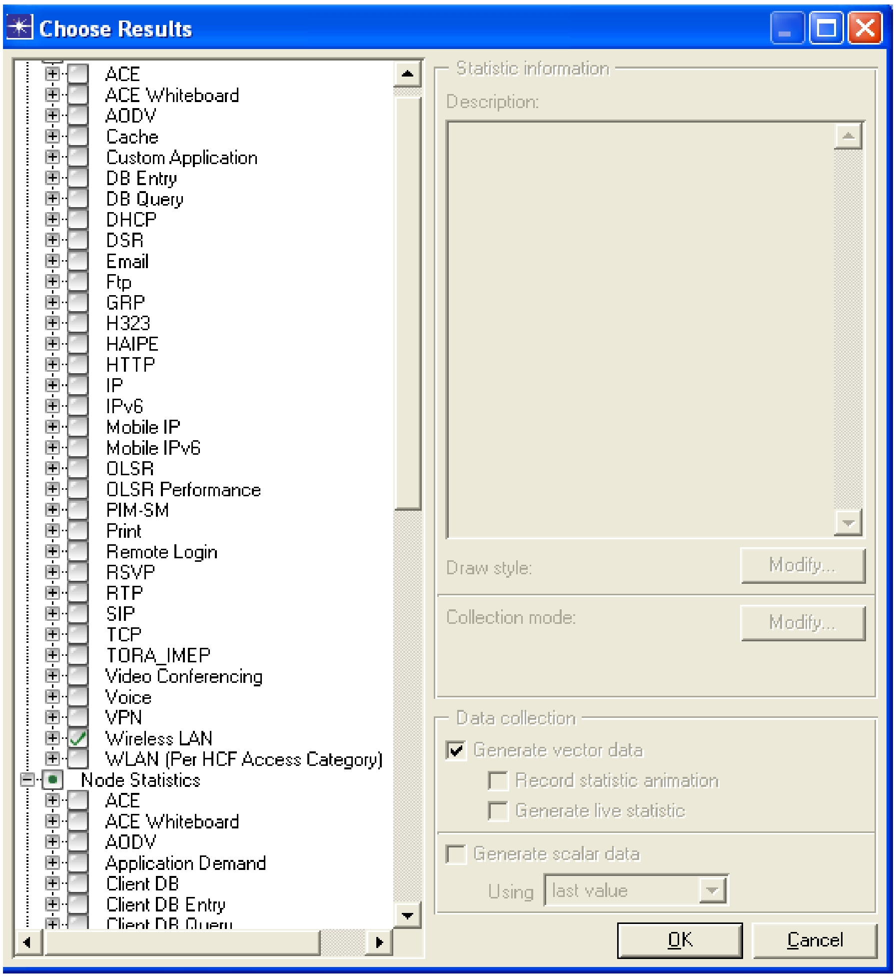


Fig 6.23 Individual Statistics

3. In the bar menu, click the run button .

4. Set the duration as one hour then press run button. (See Fig. 6.24)

5. When the simulation is done , then click the View Results button on the bar and press show .

6. Click the results for choosing all projects , then tick network, network1_trended, network1_trended1, network_trended2 these four situations.

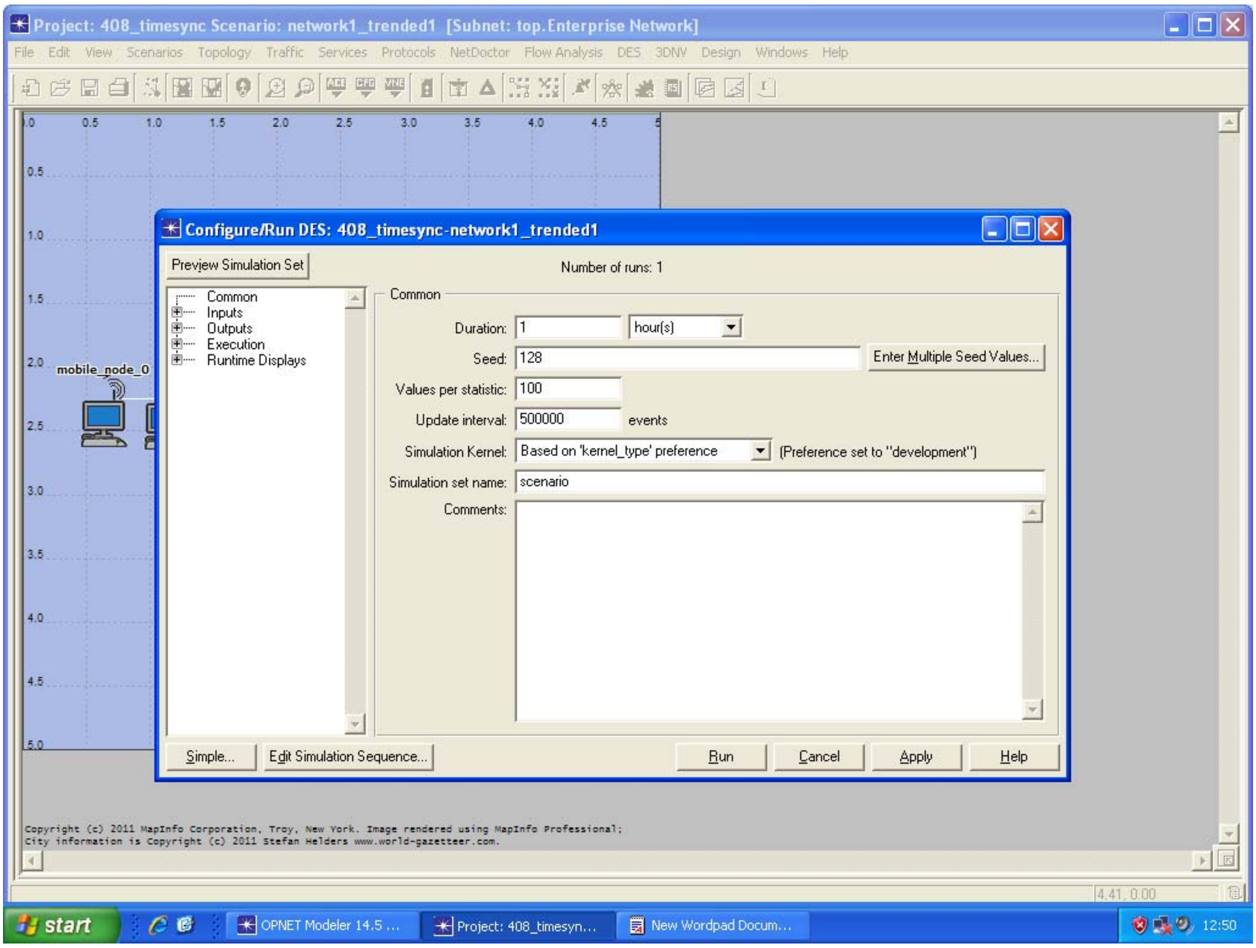


Fig. 6.24 start to process

6.7 Results

1. The first picture shows the throughput results for four different situations. See Fig. 6.25

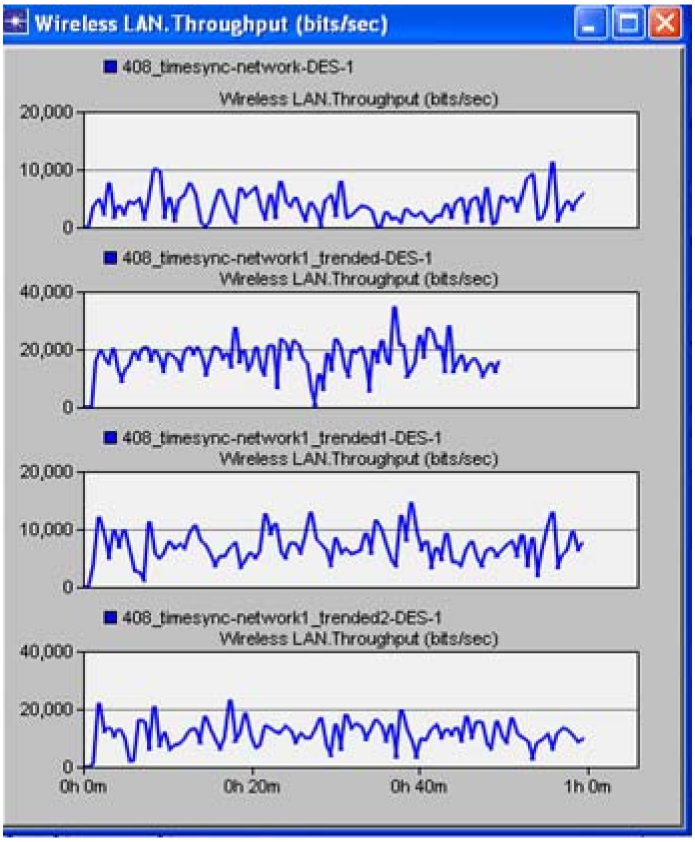


Fig 6.25 Throughput results for 4 situations

2. The Fig 6.26 shows the delay results for four situations, in these four situations , the error is less than or 2 ms as expected.

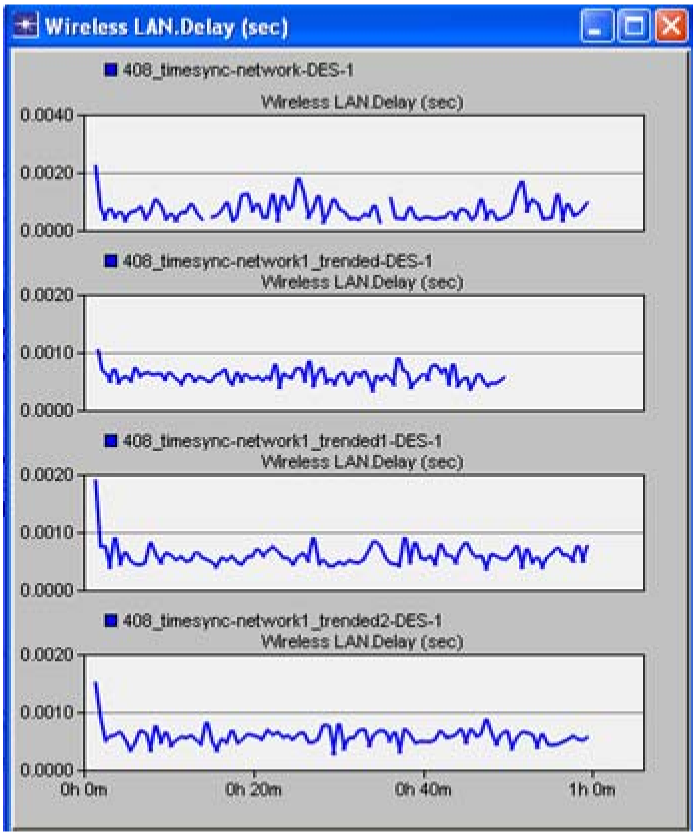


Fig 6.26 Delay Results

3. Fig 6.27 and 6.28 show load results, in each scenario there is a speed of 2.3Mbits/second from clients. With one more client the load was raised.

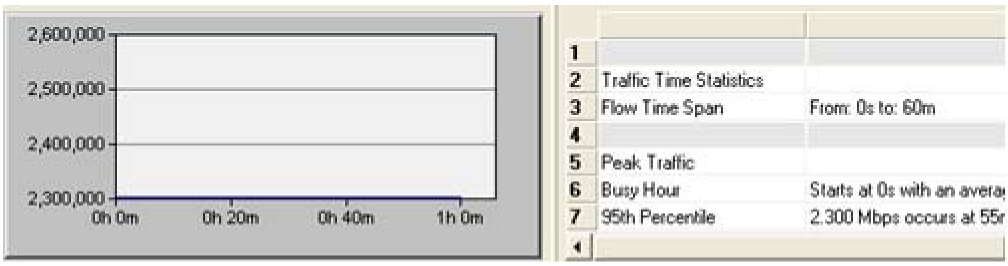


Fig 6.27 Blue line represents the load

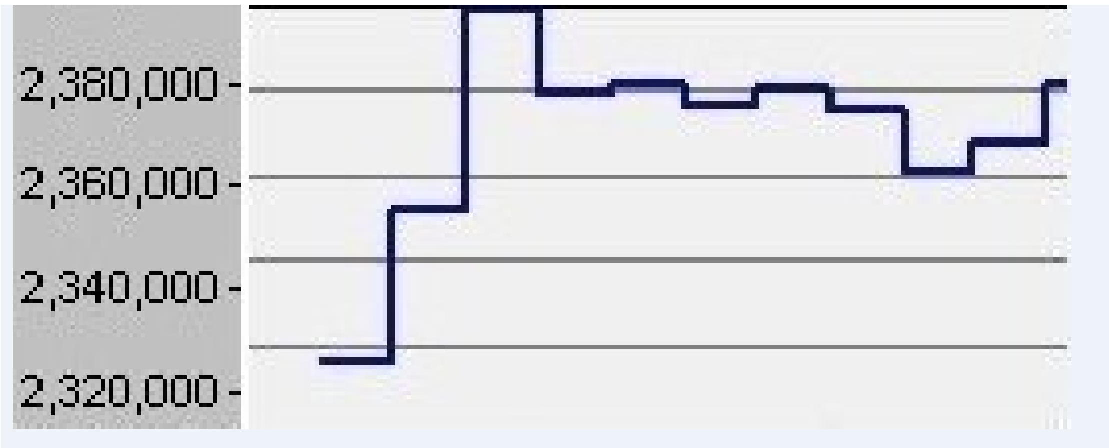


Fig 6.28 Change with the number of clients

7. Conclusion

From these results, the delay, throughput are as same as expected , with the number increasment of clients, it still keeps stable as purpose. However, the maximum number of clients could only be four due to the load pictures if clients want a stable environment.

OPNET is a great software to simulate diffierent networks. I spent one month to learn how to use it. This proejct was full of challenges. Meanwhile, I am happy to had this opportunity to know more about this field. It will help me a lot in my career in the future.

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